Improved Cu CMP process for 0.13 μ m node multilevel metallization

N. Ohashi, Y. Yamada, N. Konishi, H. Maruyama, T. Oshima, H. Yamaguchi and A. Satoh*

Device Development Center, Hitachi, Ltd.,
6-16-3, Shin-machi, Ome-shi, Tokyo 198-8512, Japan
*Hitachi ULSI Systems Co., Ltd.,
6-16-3, Shin-machi, Ome-shi, Tokyo 198-8512, Japan

Abstract

A novel two-step CMP process combining improved Cu abrasive free polishing (AFP) solution with newly developed barrier metal CMP slurry for 0.13 μ m node Cu damascene process is demonstrated. This CMP process can minimize the erosion and the dishing of Cu wiring. Further, two types of Cu residues, random Cu residue, and systematic Cu residue on patterned wafer, are eliminated with optimizing the total process design. Using these technologies, it is shown that 0.18 μ m node 7 level multilevel metallization structure is successfully formed.

Introduction

A Cu damascene process is one of the most promising technologies to realize the Cu interconnection structures for high-speed logic LSIs (1)(2). To establish Cu damascene process, CMP process of Cu and barrier metals is one of the key technologies. But, as is well known, there exist many problems to be solved in CMP process, including erosion, dishing, scratches and so on.

For these problems, we developed abrasive free polishing technology for Cu (Cu-AFP) (3)(4), and we also introduced two-step CMP process by using this new Cu-AFP into multilevel metallization with Cu damascene process (4). From these results, we have proved that Cu-AFP is effective process for damascene metallization. But we have found several problems in Cu-AFP in order to introduce this process into 0.18 μ m node Cu damascene metallization.

In this study, the advantage of improved Cu-AFP solution and newly developed barrier metal CMP slurry is demonstrated. Further, the optimized total process design for more effective application of Cu-AFP for 0.13 μ m node metallization is reported.

Experimental

Three types of Cu-AFP solutions (Hitachi Chemical, HS-C series), which do not contain abrasive, were prepared, as shown in Table 1. The solution (a) is the standard one which has been used for the production of Cu metallization (4). In the solution (b) and (c), improved corrosion inhibitor is adopted, and the volume concentration of one of the inhibitors were varied. We used hydrogen peroxide aqueous solution (H_2O_2, 30wt%) as oxidizer. The mixture ratio was optimized in the experiment, and the concentration was fixed at Cu-AFP solution: 70vol% / oxidizer: 30vol%.

The newly developed barrier metal CMP slurry (Hitachi Chemical, HS-T series) consists of chemical agents and damage free colloidal silica as abrasive. The concentration of the oxidizer (H_2O_2, 3wt%) was fixed at slurry: 92vol% / oxidizer: 8vol%.

A CMP machine (APPLIED MATERIALS, Mirra-Mesa) with 610mm diameter platens was used for all CMP process. A foamed-polyurethane-type, hard polishing pad (Rodel, IC1000) was used as a standard pad for Cu-CMP, and stacked polishing pad (Rodel, IC1400) was used as standard pad for barrier metal-CMP. Ex-situ pad dressing was carried out by using an acid-proof diamond dresser (ASAHI DIAMOND INDUSTRIAL). The Cu-AFP solution and barrier metal CMP slurry were supplied onto the polishing pad at a flow rate of 300mL/min and 200mL/min respectively.

Results and Discussion

A. Improved two-step CMP process

The removal rate of Cu film for these solutions with changing down force is plotted in Fig. 1. The platen speed was fixed at 90rpm in this experiment. So, clearly shown here, the polishing characteristics of AFP-Cu solution are changed by the type and the volume of corrosion inhibitor. The adoption of the improved corrosion inhibitor results in the increase of removal rate. On the other hand, the increase of additional corrosion inhibitor causes the drastic decrease of Cu removal rate at low down force area less than 10kPa.

Fig.2 shows the planarity in the continuous area of wide Cu lines (L/S=100 μ m/100 μ m) depending on polishing time for solution (b) and (c). This figure shows a saturation tendency of planarity (= the dishing depth) for Cu CMP polishing time. This behavior clearly shows the advantage of Cu-AFP under overpolishing. Further, the reduction of dishing depth from 110nm to 60nm is observed by using solution (c), compared with solution (b). From these results, we have proved that the characteristic of solution (c), such as the drastic decrease of Cu removal rate at low down force, leads to the reduction of dishing depth.

Fig. 3 shows the comparison of removal rate for film variety by using newly developed barrier metal CMP slurry. The down force was fixed at 14kPa, and the platen speed was fixed at 85rpm in this experiment. Clearly indicated in this figure, this slurry has very high removal selectivity of barrier metal against Cu and SiO_2 which can minimize the erosion and the dishing.

Next, we compared the electrical resistance control-ability by changing Cu wiring width treated with two-step CMP process for various polishing pads. The results are shown in Fig. 4. In this figure, it is proved that resistance control-ability of Cu wiring in Cu-AFP process strongly depends on groove type, especially in case of wide wiring pattern. The use of XY+K groove pad for Cu-AFP increases dishing depth at wide wiring width. On the other hand, we achieved good control-ability of resistance even for wide (over 20 μ m width) and narrow (under 0.2 μ m width)

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wiring width by using XY groove pad.

So, we established the improved two-step CMP process which include the minimum of the erosion and the dishing, and the excellent electrical resistance control of Cu wiring.

B. Cu residue elimination

In our study, unexpected Cu residues on patterned wafer were observed in case of adoption of Cu-AFP for the first CMP step which couldn't be eliminated by overpolishing. These Cu residues were grouped into two types. One is random Cu residue regardless of wiring pattern, and the other is systematic Cu residue which occurs in relation to pattern layout.

Fig.5 shows cross sectional SEM photograph of the random Cu residue area. As is clearly shown in this figure, this Cu residue was caused by the protuberance of underlying dielectric layer. Dielectric layer is formed with PE-TEOS stacked on PE-SiN, and the protuberance exists in PE-TEOS layer. In following experiment, however, it is proved that the protuberance is abnormal deposition of PE-TEOS which occurs with depending on the state of PE-SiN surface.

Systematic Cu residue is shown in Fig.6-a). This residue is observed at narrow and densely patterned area less than L/S=0.25 μm/0.25 μm. This Cu residue is caused by the difference of electroplated Cu film thickness between densely patterned area and blank area. The one of the ways to eliminate this kind of residue is to lower platen speed just after detection of end-point in the CMP machine. The improved result is shown in Fig.6-b). Further, improved electroplating process with the reduction of the amount of stepheight between densely patterned area and blank area, such as explained in Fig.7, leads to the increase of the process window for Cu residue elimination.

From these results, we have completely eliminated Cu residue by the optimization of total process design.

C. Multilevel Cu metallization

Fig.8 is the cross sectional SEM photograph of 7 level metallization structure in which our improved Cu CMP process is applied with the optimization of the total process design. The narrowest width of Cu wiring in this structure is 0.25 μm. As is clearly shown here, each metallization layer is completely planarized with our improved Cu CMP process, and 0.18 μm node multilevel Cu metallization structure is successfully formed.

Conclusion

The two-step CMP process by combining improved Cu-AFP solution with newly developed barrier metal CMP slurry for sub-half micron Cu damascene process was developed. Our improvement of Cu-AFP solution has excellent characteristic of high Cu removal rate and reduction of dishing depth for wiring. And the newly developed barrier metal CMP slurry has very high removal selectivity of barrier metal against Cu and SiO_2. The two-step CMP process minimizes the erosion and the dishing of Cu wiring, resulting in, the excellent electrical resistance control of Cu wiring. Further, two types of Cu residues on patterned wafer, random Cu residue regardless of wiring pattern and systematic Cu residue at densely patterned area, are eliminated with optimizing the total process design. Using these technologies, it is demonstrated that the sub-half micron Cu multilevel metallization structure is successfully formed.

So, we can conclude that these technologies have advantage for 0.13 μm node metallization.

Acknowledgments

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References

1) D.Edelesten et al., in Technical Digest of International Electron Devices Meeting in 1997, pp.773-776, Washington, DC(1997)

2) T.Hashimoto et al., in Proceedings of International Electron Device Meeting in 1998, No. 8-4, SanFrancisco, CA(1998)

3) S.Kondo et al., in Proceeding of International Interconnect Technology Conference in 2000, pp.253-255, SanFrancisco, CA(2000)

4) H.Yamaguchi et al., in Proceeding of International Interconnect Technology Conference in 2000, pp.264-266, SanFrancisco, CA(2000)

Table 1 The composition of experimental AFP-Cu.

	corrosion inhibitor	
	type	volume (%)
solution (a)	A	low
solution (b)	B	middle
solution (c)	B	high

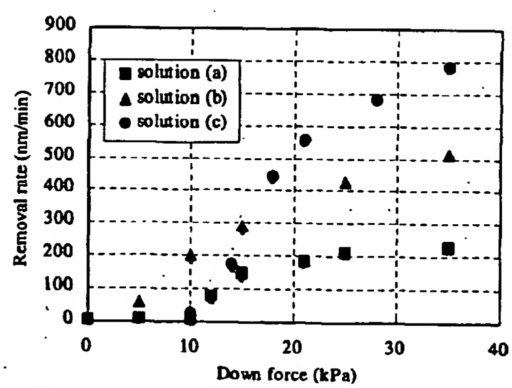

Fig. 1 The dependence of Cu removal rate on down force in AFP-Cu.

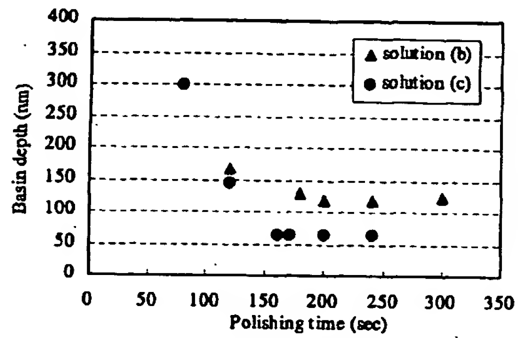

Fig. 2 The relationship between planarity and polishing time.

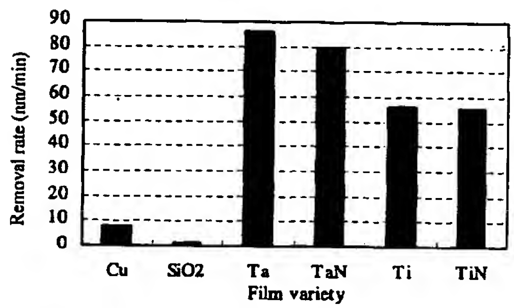

Fig. 3 The comparison of removal rate for film variety.

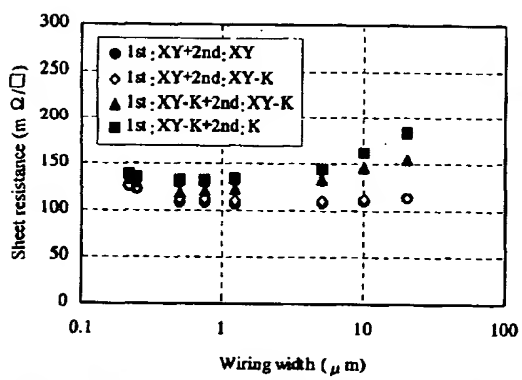

Fig. 4 The influence of polishing pad for electrical resistance control.

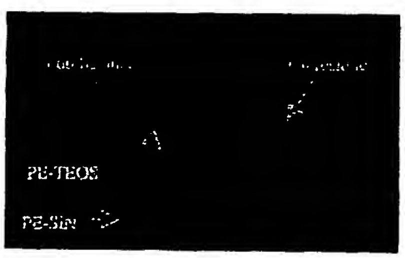

Fig. 5 Cross sectional SEM photograph of Cu residue.

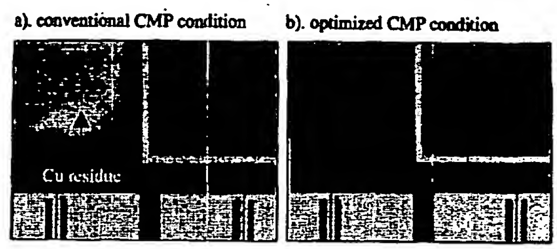

Fig. 6 External photograph of systematic Cu residue.

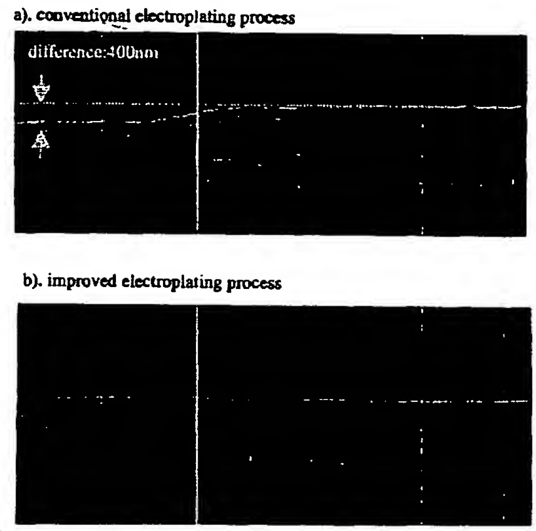

Fig. 7 Improvement of electroplating process for the difference of thickness between densely patternd area and blank area.

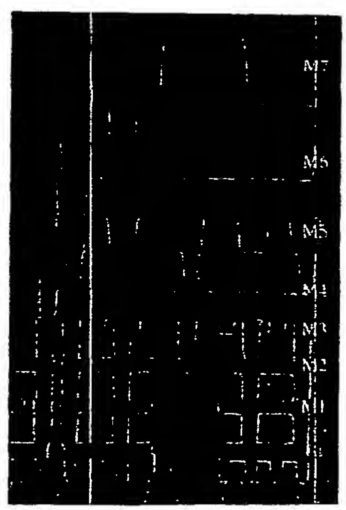

Fig. 8 Cross sectional SEM photograph of 7-level metallization structure.